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(71) Applicants:  
• **UNITED TECHNOLOGIES CORPORATION**  
Hartford, Connecticut 06101 (US)  
• **GENERAL ELECTRIC COMPANY**  
Cincinnati, Ohio 45215 (US)  
• The United States of America, represented by  
the Administrator of the National Aeronautics  
and Space Administration (NASA)  
Washington, DC 20546 (US)

(72) Inventors:  
• **Eaton, Harry E.**  
Woodstock, Connecticut 06281 (US)  
• **Allen, William P.**  
Portland, Connecticut 06480 (US)  
• **Jacobson, Nathan S.**  
Westlake, Ohio 44145 (US)

• **Bansal, Narrottam P.**  
North Olmsted, Ohio 44070 (US)  
• **Oplla, Elizabeth J.**  
Lakewood, Ohio 44107 (US)  
• **Smlalek, James L.**  
Strongsville, Ohio 44136 (US)  
• **Lee, Kang N.**  
Westlake, Ohio 44145 (US)  
• **Wang, Hongyu**  
Niskayuna, New York 12309 (US)  
• **Meschter, Peter J.**  
Niskayuna, New York 12309 (US)  
• **Spitsberg, Irene T.**  
Loveland, Ohio 45140 (US)  
• **Luthra, Krishan L.**  
Schenectady, New York 12309 (US)

(74) Representative:  
**Hiebsch, Gerhard F., Dipl.-Ing.**  
Patentanwälte,  
Dipl.-Ing. G.F. Hiebsch,  
Dipl.-Ing. N. Behrmann M.B.A. (NY),  
Heinrich-Weber-Platz 1  
78224 Singen (DE)

(54) **Silicon based substrate with environmental/thermal barrier layer**

(57) A barrier layer for a silicon containing substrate which inhibits the formation of gaseous species of silicon when exposed to a high temperature aqueous environment comprises a barium-strontium alumino silicate.

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## Description

**[0001]** The present invention relates to an article comprising a substrate containing silicon and a barrier layer which functions as a protective environmental/ thermal barrier coating and, more particularly, a barrier layer which inhibits the formation of gaseous species of Si, particularly  $\text{Si(OH)}_x$  when the article is exposed to a high temperature, aqueous (water and/or steam) environment.

**[0002]** Ceramic materials containing silicon and metal alloys containing silicon have been proposed for structures used in high temperature applications as, for example, gas turbine engines, heat exchangers, internal combustion engines, and the like. A particular useful application for these materials is for use in gas turbine engines which operate at high temperatures in aqueous environments. It has been found that these silicon containing substrates can recede and lose mass as a result of a formation volatile Si species, particularly  $\text{Si(OH)}_x$  and  $\text{SiO}$  when exposed to high temperature, aqueous environments. For example, silicon carbide when exposed to a lean fuel environment of approximately 1 ATM pressure of water vapor at  $1200^\circ\text{C}$  will exhibit weight loss and recession at a rate of approximately 6 mils per 1000 hrs. It is believed that the process involves oxidation of the silicon carbide to form silica on the surface of the silicon carbide followed by reaction of the silica with steam to form volatile species of silicon such as  $\text{Si(OH)}_x$ . Naturally it would be highly desirable to provide a external barrier coating for silicon containing substrates which would inhibit the formation of volatile silicon species,  $\text{Si(OH)}_x$  and  $\text{SiO}$ , and thereby reduce recession and mass loss.

**[0003]** Accordingly, it is the principle object of the present invention to provide an article comprising a silicon containing substrate with a barrier layer which inhibits the formation of gaseous species of Si, particularly  $\text{Si(OH)}_x$ , when the article is exposed to a high temperature, aqueous environment.

**[0004]** A second objective of this invention is to provide an article comprising a substrate with a barrier layer providing thermal protection, such layer closely matching the thermal expansion of the substrate.

**[0005]** It is a further object of the present invention to provide a method for producing an article as aforesaid.

**[0006]** The problems are solved by the teaching according to the independent claims. Particular developments are given in the dependent claims. Within the frame of the invention are all combinations of at least two of the descriptive elements and technical features disclosed in the claims and/or in the description.

**[0007]** The present invention relates to an article comprising a silicon containing substrate having a barrier layer on the substrate, wherein the barrier layer functions to both inhibit the formation of undesirable gaseous species of silicon when the article is exposed to a high temperature, aqueous environment and to provide thermal protection. By high temperatures is meant the temperature at which the Si in the substrate forms  $\text{Si(OH)}_x$  and/or  $\text{SiO}$  in an aqueous environment. By aqueous environment is meant a water and/or steam environment. The silicon containing composite is preferably a ceramic or metal alloy containing silicon. The external barrier layer is characterized by a coefficient of thermal expansion which is within plus or minus 3.0 ppm per degree centigrade of the coefficient of expansion of the silicon containing substrate. The preferred barrier layer in accordance with the present invention is a barium aluminosilicate and, preferably, a barium-alkaline earth aluminosilicate wherein the alkaline earth metal is ideally strontium. In a preferred embodiment of the present invention the article can include one or more intermediate layers between the silicon based substrate and the barrier layer. The intermediate layer(s) and serve(s) to provide enhanced adherence between the barrier layer and the substrate and/or to prevent reactions between the barrier layer and the substrate.

**[0008]** The said intermediate layer may be selected from the group consisting of  $\text{SiO}_2$ , mullite, mullite-barium strontium aluminosilicate, mullite-yttrium silicate, mullite-calcium aluminosilicate, and silicon metal. Another embodiment shows an intermediate layer selected from the group consisting of mullite, barium strontium aluminosilicate, mullite-yttrium silicate, calcium aluminosilicate and mixture thereof. The said intermediate layer may have a thickness of  $\geq 0.5$  mils (0.0005 inch), especially a thickness of 3 to 30 mils or 3 to 5 mils resp. and may comprise mullite. A bond layer is situated between the substrate and the intermediate layer preferably silicon metal or  $\text{SiO}_2$ . The thickness of the bond layer may be of between about 3 to 6 mils.

**[0009]** The invention further relates to a method for producing an article comprising a silicon containing substrate and a barrier layer which inhibits the formation of gaseous species of silicon and/or provides thermal protection when the article is exposed to a high temperature, aqueous environment as defined above.

**[0010]** The method for preparing the article comprises that the coefficient of thermal expansion of the barrier layer is within  $\pm 3.0$  ppm/ $^\circ\text{C}$  the coefficient of thermal expansion of the substrate or within  $\pm 0.5$  ppm/ $^\circ\text{C}$  the coefficient of thermal expansion of the substrate. The method is including further the step of grit blasting the substrate prior to applying the barrier layer and may include grit blast with alumina particles having a particle size of  $\leq 30$  microns, especially grit blasting at a velocity of about 150/m/sec to about 200/m/sec.

**[0011]** Another step of the invention includes preoxidizing the substrate to form a layer of  $\text{SiO}_2$  prior to applying the barrier layer, wherein preferably the preoxidizing comprises heating the substrate at a temperature of between  $800^\circ\text{C}$  to  $1200^\circ\text{C}$  for about 15 minutes to 100 hours.

**[0012]** After applying the barrier layer begins the step of heat treating the article at a temperature of about  $1250^\circ\text{C}$  for about 24 hours.

[0013] Within the frame of the invention is the step of thermal spraying while holding the substrate at a temperature of between about 870°C to 1200°C. The coefficient of thermal expansion of the barrier layer is within  $\pm 3.0$  ppm/°C the coefficient of thermal expansion of the substrate or  $\pm 0.5$  ppm/°C the coefficient of thermal expansion of the substrate.

[0014] Further advantages, characteristics and details of the invention are apparent from the following detailed description of preferred embodiments of the invention with reference to the attached drawing.

Figure 1 is a graph showing the stability of the barrier layer of the present invention with respect to recession and mass loss;

Figure 2 is a photomicrograph through a sample of the barrier layer of the present invention on a silicon carbide substrate;

Figure 3 is a photomicrograph of a sample of the barrier layer of the present invention applied to an intermediate layer on a silicon carbide substrate; and

Figure 4 demonstrates the effect of three specimens of the barrier layer of the present invention on weight loss in high temperature, aqueous environments.

[0015] The present invention relates to an article comprising a silicon containing substrate and a barrier layer, wherein the barrier layer inhibits the formation of gaseous species of silicon when the article is exposed to a high temperature, aqueous environment. The invention also relates to a method for producing the aforesaid article. In addition, it should be appreciated that while the barrier is particularly directed to an environmental barrier layer, the barrier layer also functions as a thermal barrier layer and thus the present invention broadly encompasses the use of environmental/thermal barrier layers on silicon containing substrates and on substrates having comparable thermal expansion coefficients.

[0016] According to the present invention, the silicon containing substrate may be a silicon containing ceramic substrate or a silicon containing metal alloy. In a preferred embodiment, the silicon containing substrate is a silicon containing ceramic material as, for example, silicon carbide, silicon nitride, silicon carbon nitride, silicon oxynitride and silicon aluminum oxynitride. In accordance with a particular embodiment of the present invention, the silicon containing ceramic substrate comprises a silicon containing matrix with reinforcing such as fibers, particles, and the like and, more particularly, a silicon based matrix which is fiber-reinforced. Particularly suitable ceramic substrates are a silicon carbide coated silicon carbide fiber-reinforced silicon carbide particle and silicon matrix, a carbon fiber-reinforced silicon carbide matrix and a silicon carbide fiber-reinforced silicon nitride matrix. Particularly useful silicon-metal alloys for use as substrates for the article of the present invention include molybdenum-silicon alloys, niobium-silicon alloys, and other Si containing alloys having a coefficient of thermal expansion compatible with the barrier layer of the present invention.

[0017] Barrier layers particularly useful in the article of the present invention include alkaline earth metal aluminosilicates. In accordance with a preferred embodiment, barium aluminosilicates, barium-alkaline earth metal aluminosilicates and, particularly, barium-strontium aluminosilicates are preferred. In a particular embodiment, the barrier layer comprises from about 0.00 to 1.00 mole BaO, from about 0.00 to 1.00 mole of an oxide of a second alkaline earth metal, preferably SrO, about 1.00 mole  $Al_2O_3$  and about 2.00 mole  $SiO_2$ , wherein the total of the BaO and the second alkaline earth metal or SrO is about 1.00 mole. The preferred barrier layer of the present invention comprises from about 0.10 mole to about 0.9 mole, preferably 0.25 to about 0.75 mole BaO, 0.1 mole to about 0.9 mole, preferably 0.25 to about 0.75 SrO, 1.00 mole  $Al_2O_3$  and about 2.00 mole  $SiO_2$  wherein the BaO and SrO total is about 1.00 mole. A particularly suitable barrier layer for use on silicon containing ceramic compositions in the article of the present invention comprises about 0.75 mole BaO, about 0.25 mole SrO, about 1.00 mole  $Al_2O_3$ , and about 2.00 mole  $SiO_2$ .

[0018] It is an important feature of the present invention to maintain compatibility between the coefficient of thermal expansion of the silicon containing substrate and the barrier layer. In accordance with the present invention it has been found that the coefficient of thermal expansion of the barrier layer should be within  $\pm 3.0$  ppm per degrees centigrade, preferably  $\pm 0.5$  ppm per degrees centigrade, of the coefficient of thermal expansion of the silicon containing substrate. When using a silicon containing ceramic substrate such as a silicon carbide or a silicon nitride matrix with or without reinforcing fibers as described above in combination with the preferred barium-strontium aluminosilicate barrier layer of the present invention, it is necessary to develop a stable crystallographic structure in the barrier layer of at least 50% by volume celsian in order to insure both structural integrity of the barrier layer and the desired thermal compatibility with respect to expansion coefficient between the silicon containing substrate and the barrier layer. The crystallographic structure of the barium-strontium aluminosilicate barrier layer is obtained as a result of preferred processing application and heat treating processing steps as will be described hereinbelow.

[0019] The barrier layer should be present in the article at a thickness of greater than or equal to about 0.5 mils (0.0005 inch), preferably between about 3 to about 30 mils and ideally between about 3 to about 5 mils. The barrier layer may be applied to the silicon based substrate by any suitable manner known in the art, however, it is preferable that the barrier layer be applied by thermal spraying as will be described hereinbelow.

[0020] In a further embodiment of the article of the present invention, an intermediate layer can be provided

between the silicon containing substrate and the barrier layer. The intermediate layer(s) serve(s) to provide enhanced adhesion between the barrier layer and the substrate and/or to prevent reactions between the barrier layer and the substrate. The intermediate layer consists of, for example,  $\text{SiO}_2$ , mullite, mullite-barium strontium aluminosilicate, mullite-yttrium silicate, mullite-calcium aluminosilicate, and silicon metal. Mullite has been found to be a particularly useful intermediate layer; however, mullite by itself tends to be cracked as the result of thermal spray fabrication processing. Accordingly, it is preferred that the barrier layer comprises mullite-barium strontium aluminosilicate, mullite-yttrium silicate, or mullite-calcium aluminosilicate in an amount of between about 40 to 80 wt.% mullite and between about 20 to 60 wt.% barium strontium aluminosilicate or yttrium silicate or calcium aluminosilicate. The thickness of the intermediate layer is typical to those described above with regard to the barrier layer and the intermediate layer may likewise be disposed in any manner known in the prior art, however, preferably by thermal spraying as described hereinbelow.

**[0021]** In addition to the intermediate layer, a bond layer may be provided between the silicon containing substrate and the intermediate layer. A suitable bond layer includes silicon metal in a thickness of 3 to 6 mils. Alternatively, the silicon containing substrate may be pre-oxidized to provide a  $\text{SiO}_2$  bond layer prior to application of the intermediate layer.

**[0022]** The method of the present invention comprises providing a silicon containing substrate and applying a barrier layer wherein the barrier layer inhibits the formation of gaseous species of silicon when the article is exposed to a high temperature, aqueous environment. In accordance with the present invention it is preferred that the barrier layer be applied by thermal spraying. It has been found that the barrier layer should be thermal sprayed at a temperature of between about 870°C to 1200°C in order to help equilibrate the as-sprayed, splat quenched, microstructure and to provide a means to manage stresses which control delamination. When the article being prepared in accordance with the method of the present invention is a silicon containing ceramic with a barium strontium aluminosilicate barrier layer, it is preferred that the barium strontium aluminosilicate barrier layer have celsian crystallographic structure in an amount of at least 50% by volume in the barrier layer. The formation of the celsian crystallographic structure insures compatibility between the coefficient of thermal expansion of the silicon containing ceramic and the barium strontium aluminosilicate barrier layer as described above.

**[0023]** The silicon containing substrate should be cleaned prior to application of the barrier layer to remove substrate fabrication contamination. It is preferred that the silicon based substrate be subjected to a grit blasting step prior to application of the barrier layer. The grit blasting step must be carried out carefully in order to avoid damage to the surface of the silicon-containing substrate such as silicon carbide fiber reinforced composite. It has been found that the particles used for the grit blasting should be hard enough to remove the undesired contamination but not as hard as the substrate material to prevent erosive removal of the substrate. Further, the particles must be small to prevent impact damage to the substrate. When processing an article comprising a silicon carbide ceramic composite substrate, it has been found that the grit blasting should be carried out with  $\text{Al}_2\text{O}_3$  particles, preferably of a particle size of  $\leq 30$  microns and, preferably, at a velocity of about 150 to 200 m/sec. In addition to the foregoing, it may be particularly useful to pre-oxidize the silicon based substrate prior to application of the intermediate and/or barrier layer in order to improve adherence. It has been found that bond layers of between 100 nanometers to 2000 nanometers are preferred.  $\text{SiO}_2$  bond layers of the desired thickness can be achieved by preoxidizing the silicon-carbide substrate at a temperature of between 800°C to 1200°C for about 15 minutes to 100 hours.

**[0024]** The silicon bond layer may be applied directly to the grit blasted surface by thermal spraying at approximately 870°C to a thickness of 3 to 6 mils.

**[0025]** Intermediate layers may be applied between the substrate and/or bond layer and the barrier layer or between the bond layer and barrier layer by thermal spraying in the same manner described above with respect to the barrier layer. As noted above, the preferred intermediate layers include mullite, mullite-barium strontium aluminosilicate, mullite-yttrium silicate, and mullite-calcium aluminosilicate.

**[0026]** After application of the desired layers to the silicon-based substrate material, the article is subjected to a heat treatment step in order to provide stress relief to the thermal sprayed structure, to promote bonding between the sprayed powder particles and between the layers and the substrate, and to develop the celsian phase in the BSAS barrier layer which is essentially amorphous in the as sprayed condition. The heat treatment step is carried out at a temperature of about 1250°C for about 24 hours.

**[0027]** The advantages of the article of the present invention will become clear from consideration of the following examples.

#### Example 1

**[0028]** Figure 1 shows a comparison of a hot pressed bulk specimen of BSAS, of composition  $0.75 \text{ BaO} \cdot 0.25 \text{ SrO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$  in comparison to silicon carbide thermal cycle tested 250 cycles between room temperature and 1200°C in a simulated combustion environment of high steam, lean fuel conditions. The results show 8 mg/cm<sup>2</sup> weight loss for the silicon carbide while the BSAS gains a very small amount of weight ~0.4 mg/cm<sup>2</sup>. The results show that

silicon carbide is not stable to this environment and that the BSAS system is much more stable.

#### Example 2

- 5 **[0029]** Figure 2 is a cross section of a 4 mil thick BSAS of composition  $0.75 \text{ BaO} \cdot 0.25 \text{ SrO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$  coating on SiC composite. The BSAS was thermal sprayed onto the silicon carbide composite using the following parameters:

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Parameter	Setting	
Plasma torch	Metco 3M	
Nozzle	GH	
Anode	std.	
Powder port	Metco #2	
Primary gas	Ar@80 Metco gage	
Secondary gas	H2@8 Metco gage	
Substrate temp.	850°C	
Carrier gas	Ar@37 Metco gage	
Powder feed	15 to 25 gpm	
	Intermed.	Surface
Power	30kw	25kw
Stand-off	2.5-3"	5"

- 30 **[0030]** Prior to coating the substrate was cleaned by grit blasting with 27 micron alumina particles at an impact velocity of 150 to 200 mps. As can be seen from Figure 2, the invention results in an excellent barrier layer structure.

#### Example 3

- 35 **[0031]** Figure 3 is a cross sectional view of a BSAS of composition  $0.75 \text{ BaO} \cdot 0.25 \text{ SrO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$  barrier layer on a mullite/BSAS intermediate layer of  $4 \pm 1$  mils thickness on a silicon layer on silicon carbide composite. The coating was fabricated using the following parameters.

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Plasma torch	Metco 3M		
Nozzle	GH		
Anode	std.		
Powder port	Metco #2		
Primary gas	Ar@80 Metco gage		
Secondary gas	H2@8 Metco gage		
Substrate temp.	850°C		
Carrier gas	Ar@37 Metco gage		
Powder feed	15 to 25 gpm		
	Interface	Intermed.	Surface
Power	25 kw	30kw	25kw
Stand-off	4"	2.5-3"	5"

[0032] Prior to coating the substrate was cleaned by grit blasting with 27 micron alumina particles at an impact velocity of 150 to 200 mps. As can be seen from Figure 3, the invention results in an excellent barrier layer structure.

#### Example 4

[0033] Coatings of the BSAS (barium strontium aluminosilicate) based barrier layer coating system were fabricated onto silicon carbide composite substrates having an intermediate layer as indicated below and were exposed along with an uncoated silicon carbide composite substrate (98-17A) to high pressure, combustion environment, burner rig testing similar to conditions that occur in gas turbines engines. The BSAS coatings on all samples had the following composition:  $0.75 \text{ BaO} \cdot 0.25 \text{ SrO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$ . The BSAS coatings were  $4 \pm 1$  mils in thickness and the intermediate layers were also  $4 \pm 1$  mils in thickness and were applied by thermal spraying as indicated below. These coatings consisted of variations of BSAS on mullite (98-17C) and BSAS on mullite plus BSAS (98-17B and 98-17D). Testing occurred using conditions of 1200°C test temperature, 200 hours exposure time, a fuel to air ratio of 0.053, and 6 atm pressure. After 200 hours exposure the uncoated substrate exhibited approximately 65 mg weight loss compared with weight gain of the coated coupons demonstrating that the coatings protected the substrate based on weight change data. No bond coat was used for these specimens. Thermal spray parameters were:

Parameter	Setting	
Plasma torch	Electro-plasma 03CA	
Nozzle	03CA-27	
Anode	03CA-167	
Powder port	ext. 90°	
Primary gas	Ar@14.4 SLM	
Secondary gas	He@9.8 SLM	
Substrate temp.	1050-1250°C	
Carrier gas	Ar@3-6 SLM	
Powder feed	20 gpm	
	Intermed.	Surface
Power	45kw	45kw
Stand-off	4"	4"

[0034] The results are shown in Figure 4 below which shows the effectiveness of the barrier layer of the present invention.

#### Example 5

[0035] The coefficient of thermal expansion (CTE) was measured for BSAS systems of  $0.75 \text{ BaO} \cdot 0.25 \text{ SrO} \cdot \text{Al}_2\text{O}_3 \cdot 2 \text{ SiO}_2$  having different celsian contents. Celsian content was determined by x-ray analysis of hot pressed coupons of BSAS. The celsian content affected the CTE as seen below.

% Celsian Content	CTE
5	8.1
25	7.4
95	5.2

[0036] This invention may be embodied in other forms or carried out in other ways without departing from the spirit

or essential characteristics thereof. The present embodiment is therefore to be considered as in all respects illustrative and not restrictive, the scope of the invention being indicated by the appended claims, and all changes which come within the meaning and range of equivalency are intended to be embraced therein.

## 5 Claims

1. An article comprising:
  - a substrate comprising silicon; and
  - a barrier layer, wherein the barrier layer inhibits the formation of gaseous species of Si when the article is exposed to a high temperature, aqueous environment.
2. An article according to claim 1 wherein the substrate is selected from the group consisting of silicon containing ceramic and metal alloys containing silicon.
3. An article according to claim 2 wherein the substrate is a silicon containing ceramic selected from the group consisting of silicon carbide, silicon nitride, and silicon aluminum oxynitride.
4. An article according to claim 2 wherein the substrate is a composite comprising a silicon based matrix and a reinforcing particle.
5. An article according to claim 4 wherein said substrate is selected from the group consisting of silicon carbide fiber-reinforced silicon carbide matrix, carbon fiber-reinforced silicon carbide matrix and silicon carbide fiber-reinforced silicon nitride.
6. An article according to claim 2 wherein said substrate is a silicon containing metal alloy selected from the group consisting of molybdenum-silicon alloys, niobium silicon alloys, iron-silicon alloys, and iron-nickel-silicon based alloys.
7. An article according to one of the claims 1 to 6 wherein the barrier layer comprises barium, especially barium oxide.
8. An article according to one of the claims 1 to 6 wherein the barrier layer comprises a barium aluminosilicate, especially a barium strontium aluminosilicate.
9. An article according to one of the claims 1 to 8 wherein the barrier layer comprises from about 0.00 to 1.00 moles BaO, from about 0.00 to 1.00 mole SrO, about 1.0 mole  $Al_2O_3$  and about 2.00 mole  $SiO_2$  wherein the total of BaO and SrO is about 1.00 mole.
10. An article according to one of the claims 1 to 8 wherein the barrier layer consists essentially of from about 0.00 to 1.00 mole BaO, from about 0.00 to 1.00 mole of an oxide of second alkaline earth metal about 1.00 mole  $Al_2O_3$  and about 2.00 mole  $SiO_2$  wherein BaO plus the other alkaline earth metal total 1 mole.
11. An article according to claim 9 wherein the barrier layer comprises from about 0.10 mole to about 0.90 mole BaO and from about 0.10 mole to about 0.90 mole SrO, preferably wherein the barrier layer comprises from about 0.25 mole to about 0.75 mole BaO and from about 0.25 mole to about 0.75 mole SrO.
12. An article according to claim 9 or 11 wherein the barrier layer comprises about 0.75 mole BaO and about 0.25 mole SrO.
13. An article according to claim 10 wherein the barrier layer comprises from about 0.10 mole to about 0.90 mole BaO and from about 0.10 mole to about 0.90 mole second alkaline earth oxide, preferably wherein the barrier layer comprises from about 0.25 mole to about 0.75 mole BaO and from about 0.25 mole to about 0.75 mole second alkaline earth oxide.
14. An article according to claim 10 or 13 wherein the barrier layer comprises about 0.75 mole BaO and about 0.25 mole second alkaline earth oxide.
15. An article according to one of the claims 8 to 14 wherein the crystallographic structure of the barrier layer is at least

50% by volume celsian.

16. An article according to claim 8 wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 3.0$  ppm/ $^{\circ}$ C the coefficient of thermal expansion of the substrate or wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 0.5$  ppm/ $^{\circ}$ C the coefficient of thermal expansion of the substrate.
17. An article according to claim 8 wherein the barrier layer has a thickness of  $\geq 0.5$  mils (0.0005 inch), preferably 3-5 mils.
18. An article according to one of the claims 1 to 17 including an intermediate layer between the substrate and the barrier layer.
19. An article according to claim 18 wherein said intermediate layer is selected from the group consisting of  $\text{SiO}_2$ , mullite, mullite-barium strontium aluminosilicate, mullite-yttrium silicate, mullite-calcium aluminosilicate, and silicon metal.
20. An article according to claim 18 wherein said intermediate layer is selected from the group consisting of mullite, barium strontium aluminosilicate, mullite-yttrium silicate, calcium aluminosilicate and mixtures thereof.
21. An article according to claim 20 wherein said intermediate layer comprises mullite.
22. An article according to claim 20 or 21 wherein said intermediate layer comprises from about 40 to 80 wt.% mullite and from about 60 to 20 wt.% barium strontium aluminosilicate or wherein said intermediate layer comprises from about 40 to 80 wt.% mullite and from about 60 to 20 wt.% yttrium silicate, or wherein said intermediate layer comprises from about 40 to 80 wt.% mullite and from about 60 to 20 wt.% calcium aluminosilicate.
23. An article according to claim 18 including a bond layer between the substrate and the intermediate layer.
24. An article according to claim 23 wherein the bond layer is silicon metal or  $\text{SiO}_2$ .
25. An article according to one of the claims 18 to 23 wherein the intermediate layer has a thickness of  $\geq 0.5$  mils (0.0005 inch).
26. An article according to one of the claims 8 to 15 wherein the barrier layer has a thickness of between about 3 to 30 mils, preferably a thickness of between about 3 to 5 mils.
27. An article according to one of the claims 18 to 22 wherein the intermediate layer has a thickness of 3 to 30 mils, preferably a thickness of 3 to 5 mils.
28. An article according to claim 23 or 24 wherein the bond layer has a thickness of between about 3 to 6 mils.
29. A method for preparing an article comprising the steps of:
  - providing a substrate comprising silicon; and
  - applying a barrier layer to the substrate wherein the barrier layer inhibits the formation of gaseous species of Si when the article is exposed to a high temperature, aqueous environment.
30. A method according to claim 29 wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 3.0$  ppm/ $^{\circ}$ C the coefficient of thermal expansion of the substrate or wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 0.5$  ppm/ $^{\circ}$ C the coefficient of thermal expansion of the substrate.
31. A method according to claim 24 or 30 further including the step of grit blasting the substrate prior to applying the barrier layer.
32. A method according to claim 31 including grit blast with alumina particles having a particle size of  $\leq 30$  microns, especially including grit blasting at a velocity of about 150/m/sec to about 200/m/sec.
33. A method according to one of the claims 29 to 32 including applying the barrier layer by thermal spraying.



34. A method according to one of the claims 29 to 33 including the step of preoxidizing the substrate to form a layer of  $\text{SiO}_2$  prior to applying the barrier layer, wherein preferably the preoxidizing comprises heating the substrate at a temperature of between about  $800^\circ\text{C}$  to  $1200^\circ\text{C}$  for about 15 minutes to 100 hours.
- 5 35. A method according to one of the claims 24 to 34 including heat treating at a temperature of about  $1250^\circ\text{C}$  for about 24 hours, especially including the step of, after applying the barrier layer, heat treating the article at a temperature of about  $1250^\circ\text{C}$  for about 24 hours.
- 10 36. A method according to claim 33 including thermal spraying while holding the substrate at a temperature of between about  $870^\circ\text{C}$  to  $1200^\circ\text{C}$ .
- 15 37. A method according to claim 34 wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 3.0$   $\text{ppm}/^\circ\text{C}$  the coefficient of thermal expansion of the substrate or wherein the coefficient of thermal expansion of the barrier layer is within  $\pm 0.5$   $\text{ppm}/^\circ\text{C}$  the coefficient of thermal expansion of the substrate.
- 20 38. A method according to one of the claims 29 to 37 wherein the barrier layer comprises from about 0.00 to 1.00 mole  $\text{BaO}$ , from about 0.00 to 1.00 mole  $\text{SrO}$ , about 1.00 mole  $\text{Al}_2\text{O}_3$  and about 2.00 mole  $\text{SiO}_2$  wherein the total of  $\text{BaO}$  and  $\text{SrO}$  is about 1.00 mole.
- 25 39. A method according to one of the claims 29 to 37 wherein the barrier layer consists essentially of from about 0.00 to 1.00 mole  $\text{BaO}$ , from about 0.00 to 1.00 mole of an oxide of second alkaline earth metal about 1.00 mole  $\text{Al}_2\text{O}_3$  and about 2.00 mole  $\text{SiO}_2$  wherein  $\text{BaO}$  plus the other alkaline earth metal total 1 mole.
- 30 40. A method according to one of the claims 29 to 38 wherein the barrier layer comprises from about 0.10 mole to about 0.90 mole  $\text{BaO}$  and from about 0.10 mole to about 0.90 mole  $\text{SrO}$ , especially wherein the barrier layer comprises from about 0.25 mole to about 0.75 mole  $\text{BaO}$  and from about 0.25 mole to about 0.75 mole  $\text{SrO}$ .
- 35 41. A method according to one of the claims 29 to 40 wherein the barrier layer comprises about 0.75 mole  $\text{BaO}$  and about 0.25 mole  $\text{SrO}$ .

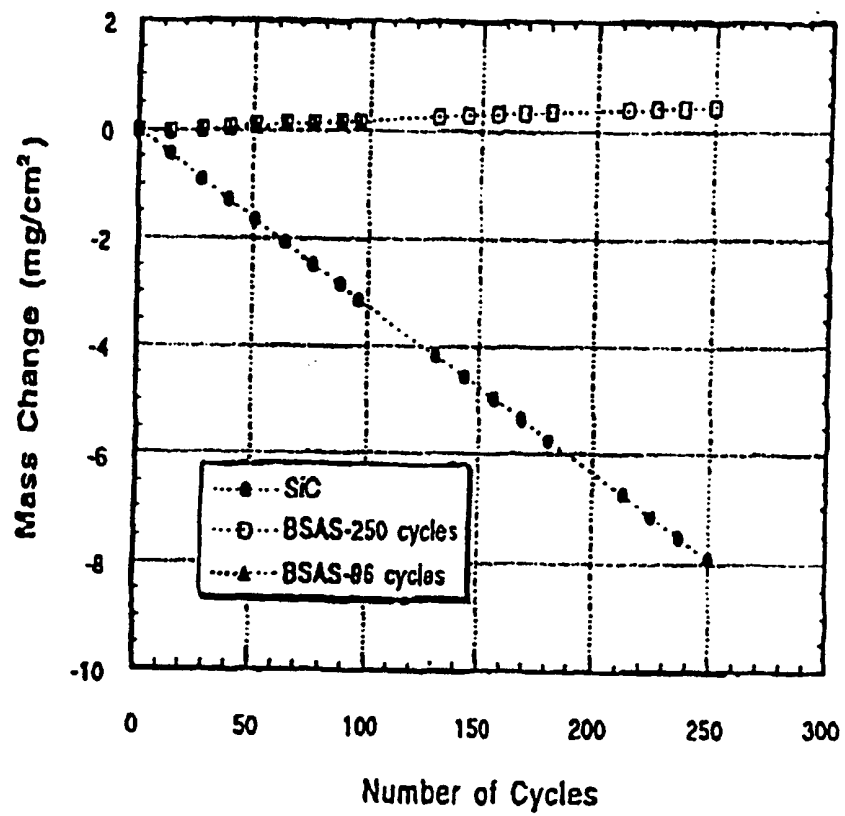
Fig. 1



Fig. 2

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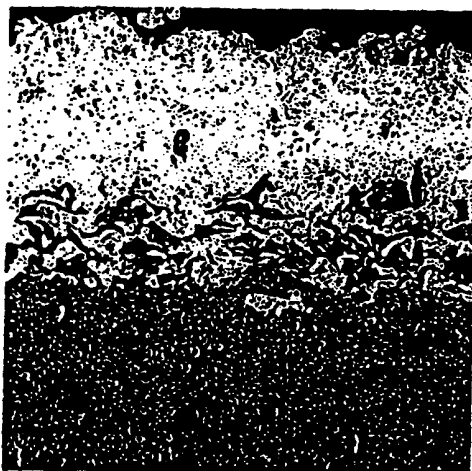


Fig. 3

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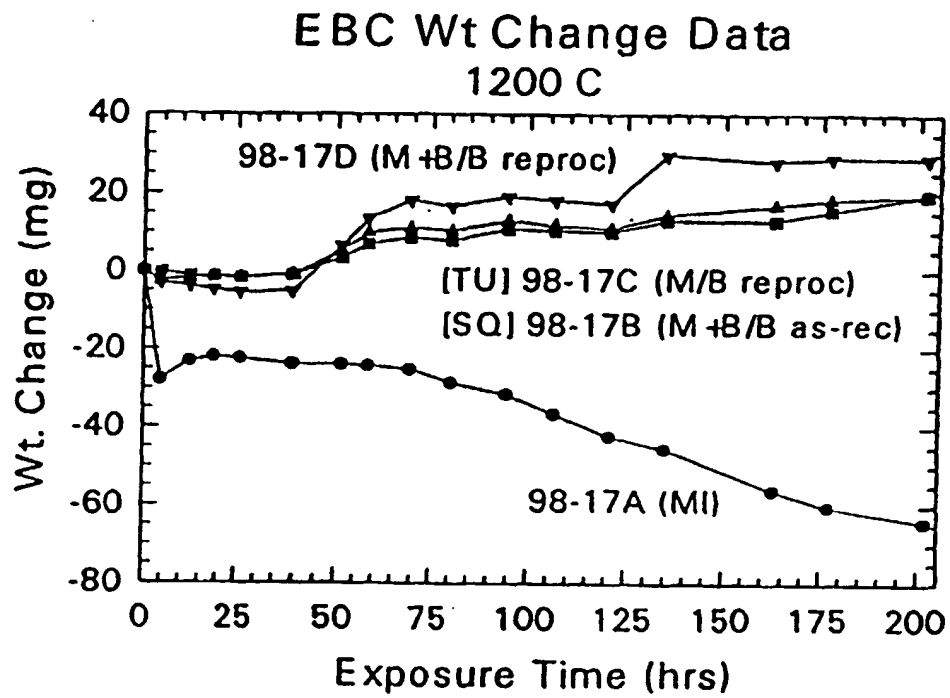


Fig. 4



European Patent  
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# EUROPEAN SEARCH REPORT

Application Number  
EP 00 10 8256

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The present search report has been drawn up for all claims			
Place of search <b>MUNICH</b>		Date of completion of the search <b>22 August 2000</b>	Examiner <b>Mini, A</b>
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons &amp; : member of the same patent family, corresponding document</p>			

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22-08-2000

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